TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 44.

ON THE RESISTANCE OF SPHERES AND ELLIPSOIDS IN WIND TUNNELS.

By

D. P. Riabouchinsky.

Translated from
Bulletin of the Aerodynamical Institute of Koutchino,
By
Paris Office, N.A.C.A.

January, 1921.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 44.

ON THE RESISTANCE OF SPHERES AND ELLIPSOIDS IN WIND TUNNELS.

By

D. P. Riabouchinsky.

Translated from
Bulletin of the Aerodynamical Institute of Koutchino,*
by
Paris Office, N.A.C.A.

In the preceding numbers of this Bulletin several Papers were devoted to the study of the influence exercised on the results of measurements by the dimensions and type of the tunnels used in aerodynamical laboratories, and on the comparison of these results with observations made in motionless and unlimited air.

With this object in view I first experimented with thin plates. The thrust exerted on these by a relative stream is fairly strictly proportional to the square of the speed and may therefore be approximately considered as not explicitly depending on viscosity. Consequently, if we call P the thrust of the stream on the plates, v the relative speed, S the surface of the plate and the surface of the section of the artificial stream, we

* No. V, p.73.

can formulate, by the theory of dynamic similitude:

$$\frac{P}{v^2 S\rho} = f\left(\frac{S}{\Sigma}\right) \tag{1}$$

The form of the function f depends on the type of tunnel and on the character of the artificial stream. In using formula (1) it must obviously not be forgotten that this formula is only exact so long as the ratio $\frac{P}{v^2 S\rho}$ does not depend on v. The resistance of a viscous fluid to the movement of a thin disk in the laminary regime is expressed, we know* as follows:

$$\frac{P}{\mu v S^{1/2}} = \frac{16}{\sqrt{\pi}} \tag{2}$$

or, if we multiply the two members of this equality by $\frac{\mu}{\rho v S^{1/2}}$

$$\frac{P}{\rho v^2 S} = \frac{16}{\sqrt{\pi}} \cdot \frac{\mu}{\rho v S^{1/2}} \tag{3}$$

The resistance of a thin disk in the hydraulic regime is approximately equal to

$$\frac{P}{v^2 \rho S} = K = 0.58 \tag{4}$$

In order to determine the critical velocity in the neighborhood of which will probably be effected the passage from law (4) to law (3), we obtain, by putting the sign of equality between the two values of $\frac{P}{v^2 \rho S}$,

$$v S^{1/2} = \frac{16}{\sqrt{\pi} \cdot 0.58}\left(\frac{\mu}{\rho}\right) = 15.6 \times \frac{\mu}{\rho}$$

* H. Lamb. Hydrodynamics. Third Edition. § 328.

Or, if we hold the kinetic viscosity of the air at 15° to be equal to

$$\frac{\mu}{\rho} = 0.0000158$$

formula (1) appears to be applicable if

$$v^2S > 0.0000000605 \qquad (5)$$

The minimum value of the ratio v^2S for the square plates which I studied was $3^2 \times (0.00123)^2 = 0.0000136$ and, therefore, appreciably exceeded the limit value determined by the inequality (5).

In the researches mentioned above I pointed out that the function f might serve, on condition that the ratio $\frac{P}{v^2S\rho}$ does not depend on the speed v, as a measuring device, for judging the quality of the tunnel. The tunnel is the more perfect as the contact between the curve $\frac{P}{\rho v^2S} = f\left(\frac{S}{\Sigma}\right)$ expressing the above-mentioned function, and the straight line $\frac{P}{\rho v^2S} = K$ is of a higher order for the limit values of the ratio $\frac{S}{\Sigma}$.

The functions f may vary appreciably for tunnels of different types. We cannot, however, attribute all the contradictions presented by the observations of different investigators to the sole difference of the tunnels in which the experiments were made. In one of my earlier studies, (Bulletin of the Aerodynamical Institute of Koutchino, No. IV, 1912, p.131) I showed that in one and the same tunnel (Prandtl tunnel) we could obtain, for expressing the relation of dependence between the pressure of the stream on a square plate and the angle of attack, two different curves (see Fig. 1, curves a and b) according to whether the wire holding the plate was fastened to the edge (curve b) or to the middle of the plate (curve a).

In the same article I showed that in the Prandtl tunnel, for expressing the relation of dependence between the pressure of the stream on a square plate and the angle of attack we can also obtain two curves (see Fig. 2) according to whether the air circulates in the tunnel (curve a) or is drawn by suction from the room into the tube (curve d).

I thought I could explain this difference in the course of the two curves by the greater fluctuations of the stream in the case in which the air is drawn directly from the room into the tunnel (without a conical nozzle or tube).

The investigation which I am describing in this article show once more what circumspection is necessary in utilizing observations made in tunnels, if we will avoid falling into too hasty generalizations.

For studying the resistance of spheres and ellipsoids in our tunnel, I had made the balance shown in Fig. 3.

The spheres and ellipsoids were of polished wood painted with ripoline; the diameter of the section of the horizontal metal rod supporting the ellipsoids was proportional to the diameter of their median sections. The spheres of 4 and 8 cm diameter were studied on the apparatus shown on page 26 of the 4th number of this Bulletin.

In this apparatus the metal rod supporting the sphere is placed perpendicularly to the stream (see Fig. 4).

The apparatus shown in Fig. 3 was used for experiments on spheres of 16 cm. and 32 cm. diameter and on ellipsoids of revolution whose median sections had diameters respectively 0.125 m. and 0.250 m., the ratios between the axes being 125:30, 250:60, 125:63, 250:125, 125:95, 250:190, 125:150, 250:300. This collection of ellipsoids can be seen on the plate forming the frontispiece of the 4th No. of the Bulletin of the Aerodynamical Institute of Koutchino.

In Fig. 6 the results of the measurements of the ellipsoids are shown graphically.

As will be seen by these curves, the linear dimensions of the ellipsoid exert, in our tunnel, an appreciable influence on the course of the curve expressing the relation of dependence between the ratios $\frac{P}{\rho v^2 S}$ and $\frac{\rho v d}{\mu}$,

In Fig. 5 we shall find the graphical expression of observations made on spheres in our tunnel, compared with observations made by other investigators.*

The first researches on the resistance of spheres in a tunnel were made by M. Loukianoff, who studied a sphere of diameter 0.076 in the old tunnel with a square section of (0.64 x 0.64) of Professor Joukovsky's laboratory at the

---

* In the studies which I quote, the temperature at which the experiments were made is not always given. The data used in tracing the curves shown in Fig. 5 were calculated for an assumed temperature of 15° C.

Imperial University of Moscow.*

The brusque change of regime observed in certain cases was pointed out (for cylinders) by M. Slessareff in 1911 at the first Russian General Congress for Aerial Navigation.

The airstreams in which M. Eiffel** and M. Maurain*** made their experiments were not bounded by solid walls. It is perhaps to the influence of such walls that the more rapid fall of the ratio $\frac{P}{\rho v^2 S}$ with the increase of speed is to be attributed in our tunnel. It is possible, however,**** that this difference is due to the greater turbulence of our stream (see above, p.4).

---

* The results obtained by M. Loukianoff are quoted from "Lessons on Aerial Navigation" (1910-11) (p.69) by Prof. Joukowsky. M. Loukianoff has lately published (Moscow 1914) a work on the resistance of the sphere and cylinder where he points out, amongst other things, that the resistance of a sphere is much greater when it is moving in motionless air.

**"Note on the Resistance of Spheres in Moving Air." Comptes Rendus de l'Académie des Sciences. Séance of Dec.30,1912.

*** Bulletin of the Aerotechnical Institute of the University of Paris, No. III, 1913.

****In a very interesting work just carried out at Prof. Prandtl's laboratory ("Der Luftwiderstand von Kugeln" Zeitschrift für Flugtechnik und Motorluftschiffahrt, May 16, 1914) C. Wieselsberger points out that in an artificial stream we can obtain two different curves for the resistance of spheres; if we take precautions that the stream be as steady as possible, we obtain a curve similar to those of Captain Costanzi (see Fig. 5); if, on the contrary, we place a wire grid in front of the sphere or apply to its surface a very thin metal ring (diameter of the section of the wire forming the ring, 1 mm.; diameter of ring, 140 mm.; diameter of sphere 280 mm.) we obtain curves similar to those of M. Eiffel and M. Maurain (see Fig. 5). Professor Prandtl explains these results by the greater turbulence of the stream in the second case.

I think there is a certain analogy between this phenomenon, which I described and explained in No. 4 of this Bulletin (1912) and which I mentioned above, p.4, and the results obtained with rough surface disks (see No. V of this Bulletin, p.30).

Captain Costanzi's investigations* were carried out in the Froude basin of the Engineer Department of Aeronautical Experiment and Construction, Rome. The dimensions of this basin are: length, 166 m.; width, 3 m.; depth, 3.6 m. The spheres on which experiments were made had diameters of 20 cm. and 10 cm. respectively. Curve b (Fig. 5) was obtained for a sphere of 20 cm. diameter, the depth of immersion of the center of the sphere being 735 mm. The extremity of the lever used for suspending the sphere is shown on Fig. 7. The lever was of lenticular section.

Curve c (Fig.5) was obtained for a sphere of 10 cm. diameter, supported by the same lever. The distance from the surface of the water to the center of the sphere was 680 mm.

Curve d was also obtained with a sphere of 10 cm. diameter, but the metal rod supporting it was of circular section. The depth of immersion was 645 mm.

Curves e and f correspond to observations made on a sphere of 10 cm. diameter held as shown in Fig. 8. The depth of immersion of the center of the sphere was 785 mm. The curve e was given by experiments made by means of a vertical rod of circular section, and curve f with a rod of lenticular section. In the latter case (curves b, c, and f) the resistance of the lever used for suspending the sphere and the perturbation caused in the water by the lever were several times smaller.

* Alcune esperienze di idrodinamica. Rendiconti delle esperienze e degli studi eseguiti nello stabilimento di esperienze et constructioni aeronautiche del Genio, No. 5, 1912.

In applying the method of variables of zero dimension to the observations of Messrs. Hesselberg and Birkeland,* I obtained the system of broken lines connecting the different observations, shown on Fig. 5. Each broken line corresponds to a sphere of determined diameter. The method of observation employed by Hesselberg and Birkeland was as follows: In the interior of a church in Christiania there were sent up small rubber balloons filled with hydrogen and attached to thin wires. By means of a chronograph, the time elapsing between the moment when the balloon was thrown up and the tension of the wire was counted. By varying the length of the wire, the velocity of the sphere was calculated by the difference of time, and, its lifting power being known, the coefficient of resistance was determined. Preliminary experiments showed that at a distance of 4 m. from the ground the speed might be considered constant. Although, in the observations of Hesselberg and Birkeland the points are not situated along a determined curve, and though they deviate appreciably from the mean values, these observations seem to be more complete than those we now possess on the resistance of spheres in free air.

A certain analogy seems to exist between the mean curve which might be made to represent the result of the observations of Hesselberg and Birkeland, and the curve expressing the relation of dependence between the torque M and the

---

* Beiträge zur Physik der freien Atmosphäre, Vol. IV, 1912.

inverse value of viscosity $\frac{1}{\mu}$ on p.27 of this number of the Bulletin.

M. Kousnetzow's coefficient of resistance (Fig. 5) was calculated by the lifting force of a sounding balloon with a diameter of 1.6 m.*

In Fig. 5 are also shown the data obtained by Mariotte, Newton, Lagerhjelm, Forselles, Kallstenius, Reich, Mendéléeff, - data which I have taken from the remarkable work "On the resistance of the Air and Aerial Navigation," by D. I. Mendéléeff.**

* Bulletin of the Aerodynamical Institute of Koutchino, No.1, p.83, 1906.

** St. Petersburg, 1880.

D. P. RIABOUCHINSKY

ON THE RESISTANCE OF SPHERES AND ELLIPSOIDS IN TUNNELS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE

DESIGNED
DRAWN 11-3-32
CHECKED
APPROVED

A 13

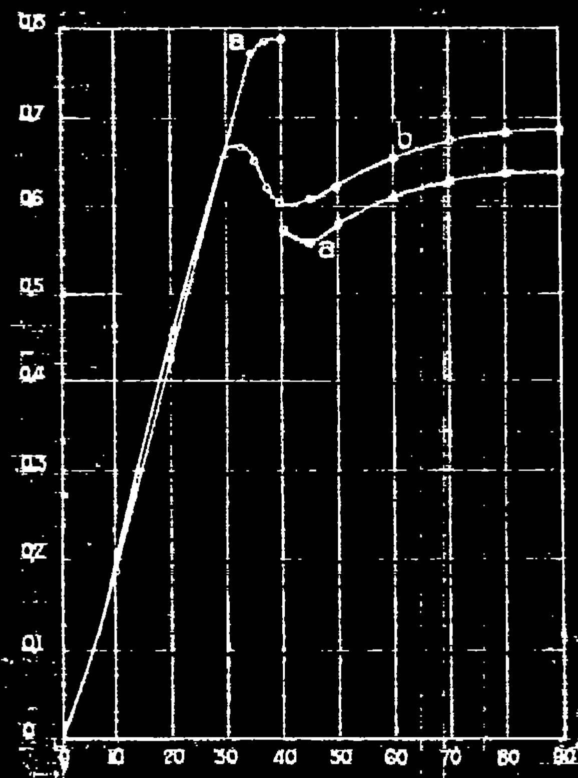


FIG. 1

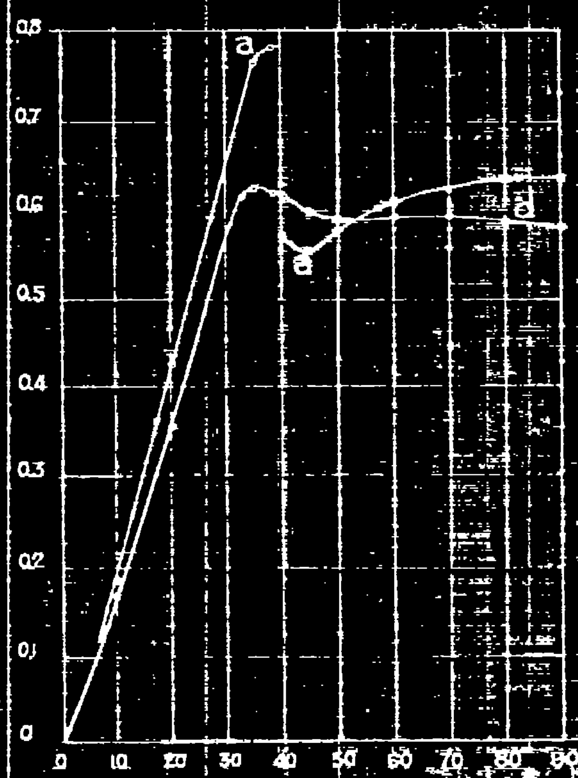


FIG. 2

D. R. RIABOUCHINSKY

ON THE RESISTANCE OF SPHERES AND ELLIPSOIDS IN TUNNELS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE

DESIGNED
DRAWN
CHECKED
APPROVED

A 14

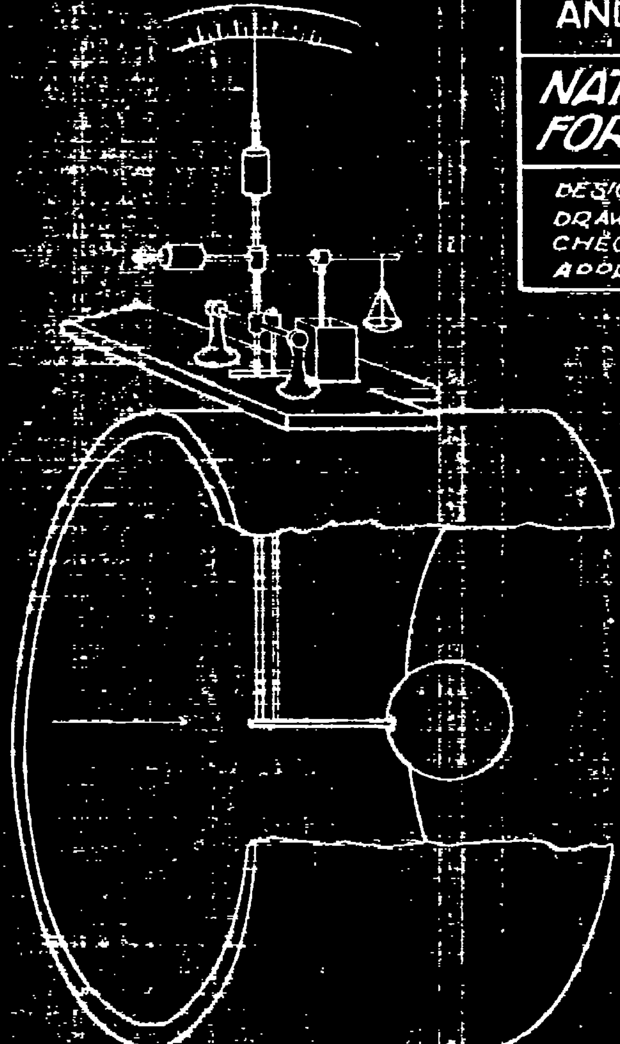


FIG. 3

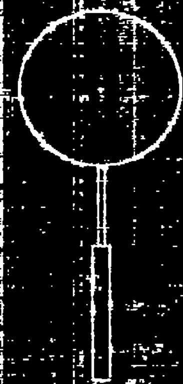


FIG. 4

FIG. 7

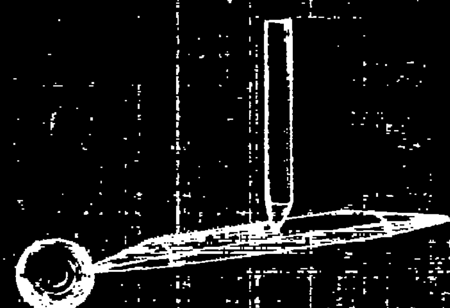


FIG. 8

D.P. RIABOUCHINSKY

ON THE RESISTANCE OF SPHERES AND ELLIPSOIDS IN TUNNELS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE

DESIGNED DRAWN 11-1-26 CHECKED APPROVED	A 15

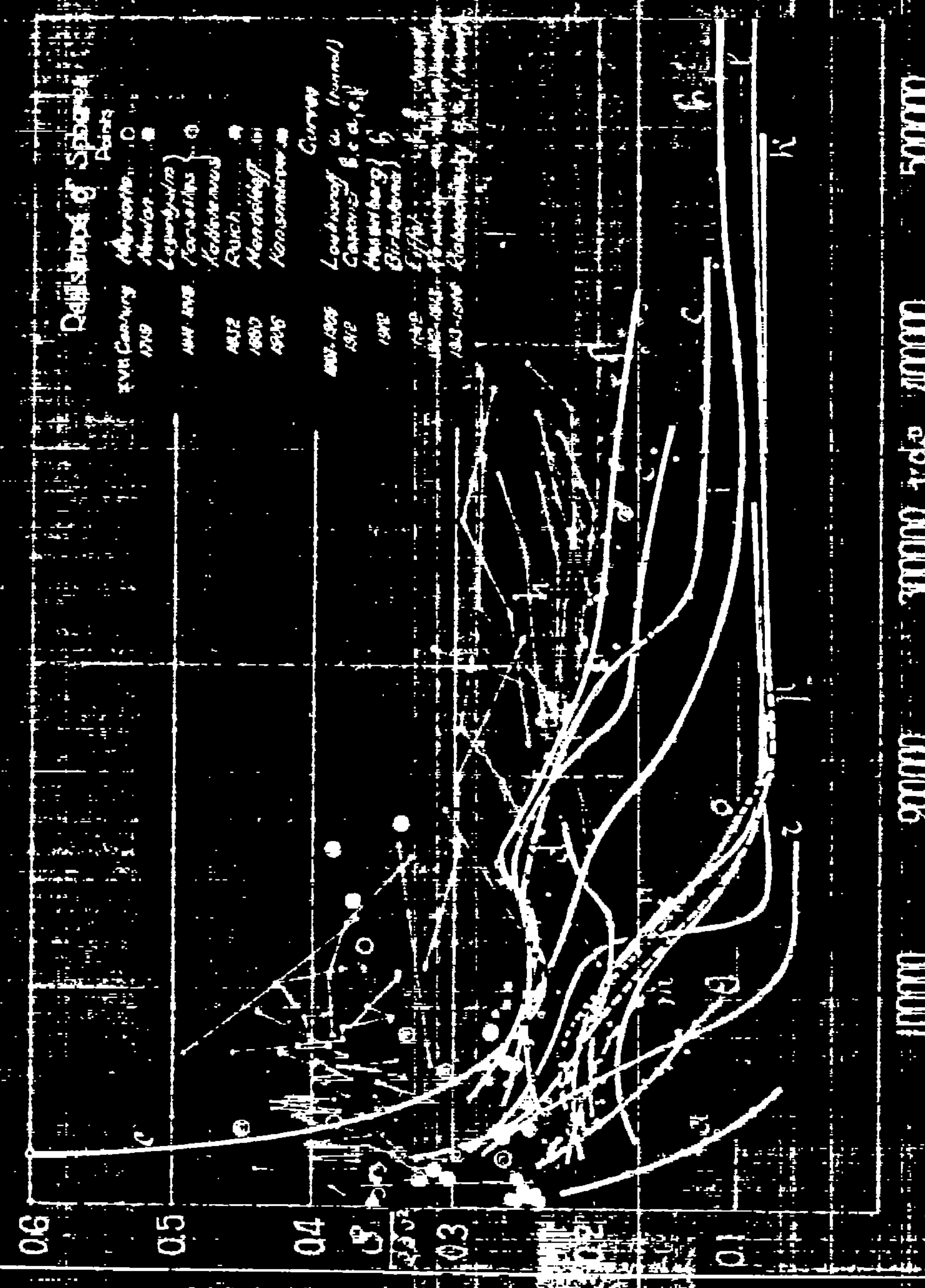
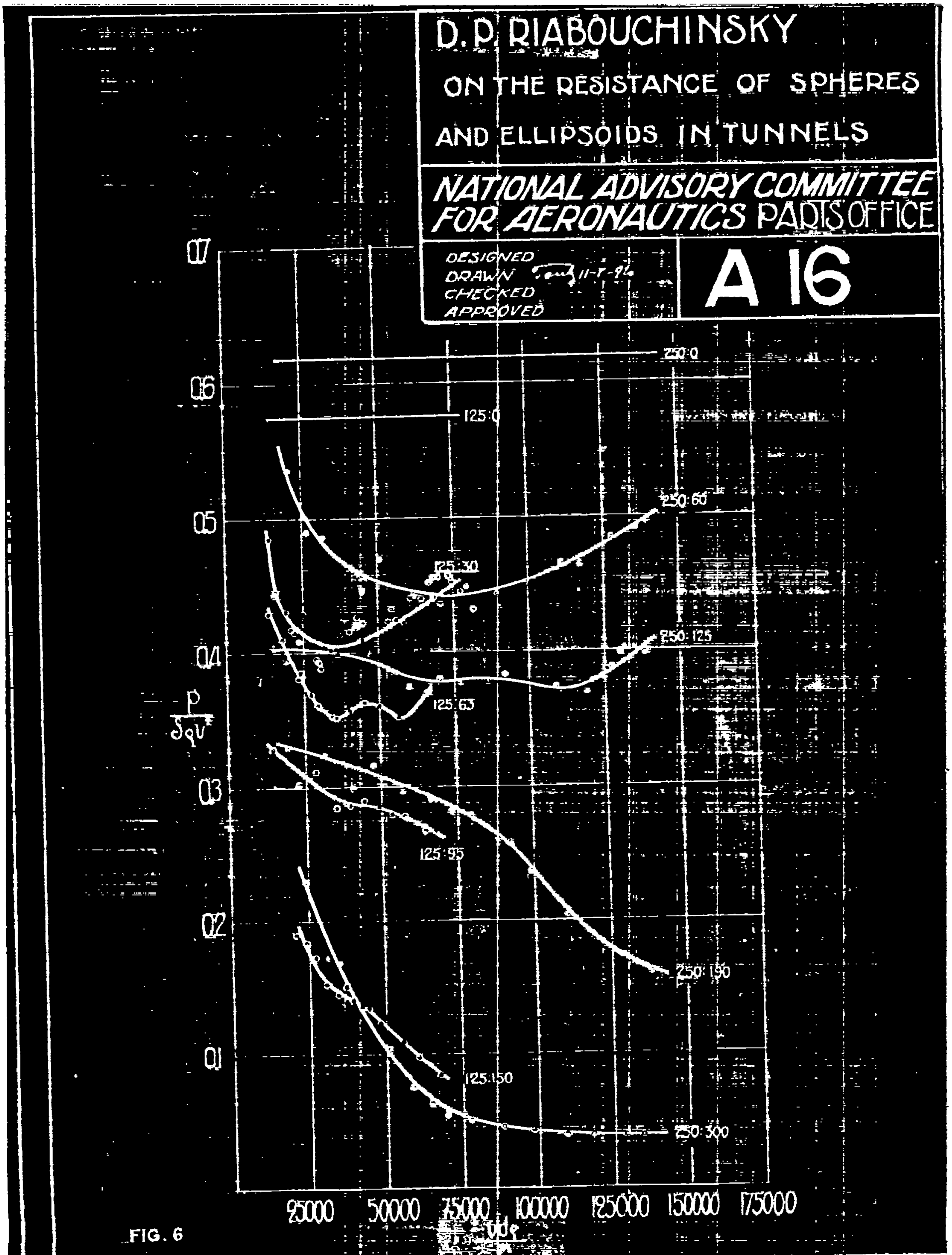


FIG. 5



D. P. RIABOUCHINSKY
ON THE RESISTANCE OF SPHERES AND ELLIPSOIDS IN TUNNELS
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE
DESIGNED
DRAWN 11-7-24
CHECKED
APPROVED
A 16
0.7
0.6
0.5
0.4
0.3
0.2
0.1
$\frac{P}{S\rho V^2}$
250:0
125:0
250:60
125:30
250:125
125:63
125:95
250:190
125:150
250:300
25000
50000
75000
100000
125000
150000
175000
$Vd\rho$

FIG. 6